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BARD Project Number: IS-2887-98R

Project Title: Estimation of Energy Expenditure of Free Living and Growing Domesticated Ruminants by Heart Rate Measurement

Investigators	**Institutions**
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Keywords *not* appearing in the title and in order of importance. Avoid abbreviations.

Abbreviations commonly used in the report, in alphabetical order**:**

Budget: IS: $ US: $ Total: $

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Signature
Principal Investigator

Signature
Authorizing Official, Principal Institution

Publication Summary (numbers)

	Joint IS/US authorship	US Authors only	Israeli Authors only	Total
Refereed (published, in press, accepted) BARD support acknowledged			2	2
Submitted, in review, in preparation		2	2	4
Invited review papers				
Book chapters				
Books				
Master theses			1	1
Ph.D. theses			1	1
Abstracts		2	3	5
Not refereed (proceedings, reports, etc.)			1	1

Postdoctoral Training: List the names and social security/identity numbers of all postdocs who received more than 50% of their funding by the grant.

Cooperation Summary (numbers)

	From US to Israel	From Israel to US	Together, elsewhere	Total
Short Visits & Meetings		1 week	1week	2 week
Longer Visits (Sabbaticals)	6 weeks			6 weeks

Description Cooperation:
The USA and the Israeli teams coordinated the range of diets, of reproductive states and of environment conditions to which animals had been exposed. The stability of the O2 pulse and factors that could affect it was the comparison basis for both teams. When these were found to be affected by a specific factor, such as the heat load, in the work of one team – the other team was focused as well on this factor in its work. In general, results and conclusions from experiments were transferred between the teams on a regular basis, and discussed in personal meetings in few occasions to adjust together the experiments in both locations.

Patent Summary (numbers)

	Israeli inventor only	US inventor only	Joint IS/US inventors	Total
Submitted				
Issued (allowed)				
Licensed				

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Estimation of energy expenditure of free living and growing domesticated ruminants by heart rate measurement

A. Brosh, D. Robertshaw, Y. Aharoni, Z. Holzer, M. Gutman, A. Arieli.

ABSTRACT BARD EE&HRfinalReport.doc

Research objectives were: 1) To study the effect of diet energy density, level of exercise, thermal conditions and reproductive state on cardiovascular function as it relates to oxygen (**O_2**) mobilization. 2) To validate the use of heart rate (**HR**) to predict energy expenditure (**EE**) of ruminants, by measuring and calculating the energy balance components at different productive and reproductive states. 3) To validate the use of HR to identify changes in the metabolizable energy (**ME**) and ME intake (**MEI**) of grazing ruminants.

Background: The development of an effective method for the measurement of EE is essential for understanding the management of both grazing and confined feedlot animals. The use of HR as a method of estimating EE in free-ranging large ruminants has been limited by the availability of suitable field monitoring equipment and by the absence of empirical understanding of the relationship between cardiac function and metabolic rate. Recent developments in microelectronics provide a good opportunity to use small HR devices to monitor free-range animals. The estimation of O_2 uptake (**VO_2**) of animals from their HR has to be based upon a consistent relationship between HR and VO_2. The question as to whether, or to what extent, feeding level, environmental conditions and reproductive state affect such a relationship is still unanswered. Studies on the basic physiology of O_2 mobilization (in USA) and field and feedlot-based investigations (in Israel) covered a variety of conditions in order to investigate the possibilities of using HR to estimate EE. **In USA** the physiological studies conducted using animals with implanted flow probes, show that: 1) although stroke volume decreases during intense exercise, VO_2 per one heart beat per $kgBW^{0.75}$ (O_2 Pulse, **O2P**) actually increases and measurement of EE by HR and constant O2P may underestimate VO_2, unless the slope of the regression relating to heart rate and VO_2 is also determined, 2) alterations in VO_2 associated with the level of feeding and the effects of feeding itself have no effect on O2P, 3) both pregnancy and lactation may increase blood volume, especially lactation; but they have no effect on O2P, 4) ambient temperature in the range of 15 to 25°C in the resting animal has no effect on O2P, and 5) severe heat stress, induced by exercise, elevates body temperature to a sufficient extent that 14% of cardiac output may be required to dissipate the heat generated by exercise rather than for O_2 transport. However, this is an unusual situation and its affect on EE estimation in a freely grazing animal, especially when heart rate is monitored over several days, is minor. **In Israel** three experiments were carried out in the hot summer to define changes in O2P attributable to changes in the time of day or in the heat load. The animals used were lambs and young calves in the growing phase and highly yielding dairy cows. In the growing animals the time of day, or the heat load, affected HR and VO_2, but had no effect on O2P. On the other hand, the O2P measured in lactating cows was affected by the heat load; this is similar to the finding in the USA study of sheep. Energy balance trials were conducted to compare MEI recovery by the retained energy (**RE**) and by EE as measured by HR and O2P. The trial hypothesis was that if HR reliably estimated EE, the MEI proportion to (EE+RE) would not be significantly different from 1.0. Beef cows along a year of their reproductive cycle and growing lambs were used. The MEI recoveries of both trials were not significantly different from 1.0, 1.062±0.026 and 0.957 ±0.024 respectively. The cows' reproductive state did not affect the O2P, which is similar to the finding in the USA study. **Pasture** ME content and animal variables such as HR, VO_2, O2P and EE of cows on grazing and in confinement were measured throughout three years under twenty-nine combinations of herbage quality and cows' reproductive state. In twelve grazing states, individual faecal output (**FO**) was measured and MEI was calculated. Regression analyses of the EE and RE dependent on MEI were highly significant ($P<0.001$). The predicted values of EE at zero intake (78 $kcal/kgBW^{0.75}$), were similar to those estimated by NRC (1984). The EE at maintenance condition of the grazing cows (EE=MEI, 125 $kcal/kgBW^{0.75}$) which are in the range of 96.1 to 125.5 as presented by NRC (1996 pp 6-7) for beef cows. Average daily HR and EE were significantly increased by lactation, $P<0.001$ and $P<0.02$ respectively. Grazing ME significantly increased HR and EE, $P<0.001$ and $P<0.001$ respectively. In contradiction to the finding in confined ewes and cows, the O2P of the grazing cows was significantly affected by the combined treatments ($P<0.001$); this effect was significantly related to the diet ME ($P<0.001$) and consequently to the MEI ($P<0.03$). Grazing significantly increased O2P compared to confinement. So, when EE of grazing animals during a certain season of the year is estimated using the HR method, the O2P must be re measured whenever grazing ME changes. A high correlation ($R^2>0.96$) of group average EE and of HR dependency on MEI was also found in confined cows, which were fed six different diets and in growing lambs on three diets. **In**

conclusion, the studies conducted in USA and in Israel investigated in depth the physiological mechanisms of cardiovascular and O_2 mobilization, and went on to investigate a wide variety of ruminant species, ages, reproductive states, diets ME, time of intake and time of day, and compared these variables under grazing and confinement conditions. From these combined studies **we can conclude** that EE can be determined from HR measurements during several days, multiplied by O2P measured over a short period of time (10-15 min). The study showed that RE could be determined during the growing phase without slaughtering. In the near future the development microelectronic devices will enable wide use of the HR method to determine EE and energy balance. It will open new scopes of physiological and agricultural research with minimizes strain on animals. The method also has a high potential as a tool for herd management.

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Achievements

The first goal of this BARD project was to examine the reliability of using heart rate (**HR**) calibrated to oxygen consumption (**VO_2**) to estimate the energy expenditure (**EE**) of free range animals. The second goal was to examine whether HR and HR calibrated to VO_2 could be used to estimate the metabolizable energy intake (**MEI**) and consequently the entire energy balance of free-living animals. So far there has been no practical available method to measure the retained energy (**RE**) of growing free-range animals without slaughtering the animal. In addition, the available method, the comparative slaughtering technique (Lofgreen 1968), can estimate the accumulated RE for a long period of time, but cannot estimate RE for a specific short period of time.

Brosh et al. (1998) showed that the calculation of EE from HR measurement during the day multiplied by a constant individual measured value of oxygen (**O_2**) consumption per one heart beat (**O2P**, calculated in this report as: (ml O2/(beat*kgBW$^{0.75}$)) is preferable for estimating EE by HR measurements to the regression equation of VO_2 per HR during exercise. Thus, the axis around which the study was conducted was the examination of O2P stability under a variety of conditions.

From the physiological studies conducted using animals with implanted flow probes, it can be concluded that:

1) Although stroke volume decreases during intense exercise (Figure 3, Appendix 1.), O2P actually increases (Figure 4, Appendix 1.), and measuring HR may underestimate VO_2 unless the slope of the regression relating to heart rate and VO_2 is also determined (Figure 1, Appendix 1.).

2) Alterations in VO_2 associated with the effects of feeding have no effect on O2P.

3) Although both pregnancy and lactation may increase blood volume, especially lactation, they have no effect on oxygen pulse.

4) Ambient temperature in the range of 15 ^{o}C to 25 ^{o}C in the resting animal has no effect on oxygen pulse.

5) Severe heat stress, especially that associated with an elevated rectal temperature induced by exercise at an excess of 60% of maximal VO_2 for a period of 15 min, may elevate body temperature to a sufficient extent that 14% of cardiac output is required to dissipate the heat of exercise (Figures 8,10-13, Appendix 1). However, this is an unusual situation in a freely grazing animal, and such periods of exercise are transient

in nature. Therefore the use of a heart rate monitor to measure metabolism will not be significantly impacted, especially when heart rate is monitored over periods of several days or even weeks, on account of the transitory nature of such events.

When the HR method is used to estimate EE, many factors such as environment, diet, reproductive and productive states can affect O2P; these factors can be corrected by re measuring O2P for each animal in its specific conditions. But when the O2P of free-living animals is measured in constrained standing animals, it should be measured for a short and limited time. The short measurement should represent the O2P of the entire day or days of HR measurement. If O2P changes during the day, the O2P measured over a short period of time may not represent the O2P of the entire day and this may bias the EE estimation. In order to evaluate this issue we measured the O2P of calves and lambs in the growing phase several times around 24 h of the day (Aharoni 2002). The studies in USA show that heat load could increase blood flow for the purpose of heat dissipation. This increase in blood flow can bias the O2P measurement to about 14% below the estimation of the O2P measured in comfortable conditions.

To address this problem we conducted the 24 h measurement of O2P in the middle of the hot summer. In the trial we covered the hot and the cool hours of the day.

We also measured the O2P of high yielding dairy cows, starting in the spring and continuing to the hot summer. High yielding cows produce a lot of intrinsic heat, and the combination of intrinsic and external heat load can imitate the USA measurement conditions in which sheep were exposed to a high intrinsic heat load due to intense exercise. We also measured the O2P of grazing and confined sheep during the summer (Landau, unpublished). Those sheep were first grazed on stubble and their MEI was measured, later the same sheep were kept in confinement and were fed a diet which led them to consume similar MEI as that consumed by the grazing sheep. The O2P of the grazing sheep was measured outside under solar radiation during the hot hours of the day. The O2P of the confined sheep was measured in the same hours of the day, but the sheep were protected from solar radiation.

For the calves and lambs, HR and VO2 significantly changed during the day, but O2P did not change in spite of the significant change in heat load during the 24 h of the day (Aharoni 2002). For the dairy cow, the combination of high intrinsic and high external heat load caused a reduction of about 18 % in O2P compared to the maximal O2P value (Aharoni 2002). The O2P of the grazing sheep (0.22±0.01) was lower by 15% than that of the same sheep when they were kept in confinement and protected from solar radiation (0.26±0.01). This reduction in O2P is almost identical to the value of 14% increase in blood flow for the purpose of heat dissipation, which was measured for sheep after exercise in the USA. It can be concluded that O2P is usually stable during the day, but when animals were exposed to a high heat load, the effect of the extreme heat load, intrinsic and extrinsic, on the O2P should be corrected.

The above-presented studies were designed to investigate the stability of O2P and the physiological mechanism of the O_2 mobilization under specific artificial conditions that represent a variety of conditions to which animals are naturally exposed. It is difficult to simulate the effects of every possible factor or complex interaction between factors on O2P. To examine the reliability of the HR method under un-expected conditions we carried out two energy balance trials. The trials represent common basic states of animals during their life, reproductive cycle and growth. The energy balance trials were conducted to calculate MEI recovery by RE and EE as measured by HR and O2P. The trial hypothesis was that if HR reliably estimated EE, the MEI proportion to (EE+RE) would not be significantly different from 1.0.

Beef cows along a year of their reproductive cycle (Brosh et al. 2002) and growing lambs (Arieli et al. 2002) were used. The rates of MEI recovery in both trials were not significantly different from 1.0, 1.062±0.026 and 0.957±0.024 respectively. The cows' reproductive state and the dietary ME fed to the cows and to the lambs did not affect O2P; these findings were similar to the results of the USA study.

The third objective of the trial was to validate the use of HR and EE (measured by HR) to identify changes in the metabolizable energy (**ME**) fed to the animals and to quantify the ME intake (**MEI**). Data of three trials were used to address the above aims.

In the first study (Brosh et al. Appendix 2) pasture ME content and variables such as HR, VO_2, O2P and EE in grazing and in confinement (of the same grazing cows) were measured throughout three years under twenty-nine combinations of herbage quality and cows' reproductive states (Table 1 Appendix 2). In twelve grazing states, individual faecal output (**FO**) was measured and MEI was calculated. Regression analyses of the EE and RE dependent on MEI (Figure 9, Appendix 2) were highly significant (P<0.001). The predicted values of EE at zero intake (328 kJ/kgBW$^{0.75}$, i.e. 78 kcal/kgBW$^{0.75}$) were similar to those estimated by NRC (1984), 77 kcal/kgBW$^{0.75}$. The EE of the grazing cows at maintenance condition (EE=MEI, 523 kJ/kgBW$^{0.75}$, i.e. 125 kcal/kgBW$^{0.75}$) was consistent with NRC (1996 pp 6-7) a range of 96.1 to 125.5. Average daily HR and EE were significantly increased by lactation, P<0.001 and P<0.02 respectively (Table 4, Appendix 2). Grazing ME significantly increased HR and EE, P<0.001 and P<0.001 respectively. In contradiction to the finding in confined sheep and cows, the O2P of the grazing cows was significantly affected by the treatments (P<0.001); this effect was significantly related to diet ME (P<0.001) and consequently to MEI (P<0.03). Grazing significantly increased O2P compared to confinement. Thus, when EE of grazing animals during a certain season of the year is estimated using the HR method, O2P must be re measured whenever the ME of grazing herbage changes. A high correlation (R^2>0.95) of EE and of HR dependency on MEI was also found in confined cows, which were fed six different diets (Shargal et al. Appendix 3), in confined cow during a year of reproductive cycle (Brosh et al. 2002), and in growing lambs on three diets (Barkai et al. 2002).

In conclusion, the studies conducted in USA and in Israel investigated in depth the physiological mechanisms of cardiovascular and O_2 mobilization, and went to investigate a wide variety of ruminant species, ages, reproductive states, diets ME, time of intake and time of day, and compared these variables under grazing and confinement conditions. From these combined studies we can conclude that EE can be determined from HR measurements conducted in the course of several days, multiplied by O2P measured over a short period of time (10-15 min). The study showed that RE could be determined during the growing phase without slaughtering the animals. In the near future the development of microelectronic devices will enable wide use of the HR method to determine EE and energy balance. It will open new scopes of physiological and agricultural research with minimal strain on the animals. The method is also potentially a very helpful tool for herd management.

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